Sounds and Space

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Where are sounds and where do we experience them to be? In what follows I argue that when we hear them sounds are where we are, but that we don't hear them to be where we are because we don't hear them to be anywhere. This conclusion follows from the account I give (in section 1) of what sounds are and (in section 2) of the role of space in auditory perception.

1. What are sounds?

The function of auditory perception

We have perceptual systems because they are useful, and they are useful because they tell us things about our environment and about what is happening in our environment. Auditory perception is no exception: it tells us about objects and events in our environment by detecting disturbances in the air caused by those objects and events.

In what follows I am going to talk about the perception of what may be labelled 'ecological' sounds and their sources – those sounds produced by naturally occurring events or various kinds. I am going to ignore the role of sounds in communication and in the perception of music. Although both depend on the more fundamental processes involved in ecological sound perception that I am going to describe (and to the extent that they don't depend on those more fundamental processes they are distinct perceptual systems) they raise specific problems that I will not go into here.

Auditory perception tells us about objects and events in our environment and the sounds produced by those objects and events. When we hear a sound we can attend to the source of the sound and its properties – what it is, how it is, where it is, whether it is moving, and so on – or we can attend to the sound itself and its properties – its pitch, timbre, loudness, and so on. Although relatively little investigation has been done to determine how good we are at perceiving and recognising sound sources, that which has been done has found that we are surprisingly good at both.

For example, we can perceive the size of an object dropped into water; that something is rolling; we can tell the material composition of an object from the sound of an impact; we can tell the force of an impact; we can distinguish objects with different shapes; we can tell the length of a rod dropped onto the floor; when something is dropped we can hear whether it bounced or broke; we are good at recognising natural sounds such as footsteps, hands clapping, paper tearing, and so on; we can tell that a cup is being filled and when it is full. These are all examples that have been empirically demonstrated; it would be possible to find many more.[1]

Ecological sounds themselves, rather than their sources, are not very interesting; for many ecological sounds it is actually rather difficult to attend to the sound rather than to the source of the sound and we are poor at describing the properties of the sound as opposed to the source of the sound (we tend to describe the sounds in terms of their sources – 'it's like the sound made by…).[2] It is easy to overlook this about our perception of ecological sounds because we have become so used to hearing artificially produced sounds for which it isn't true (or for which the opposite is true).

We can perceive these various things about the sources of sounds because auditory perception functions to tell us about the sources of the sounds we hear, and our auditory experience is of, or represents, the sources of sounds and their properties as well as sounds and their properties. It does so, I shall argue, by representing sounds as having been produced by their sources.

The sources of sounds

To understand how auditory perception carries out its function of telling us about the sources of sounds we need to start with how the things that produce sounds – the sources of sounds – do so. Sounds can be produced by different kinds of things – liquids, material objects, strings, air movement – and in different ways; for simplicity I

[1] See, for example, Carello et al. 1998 and 2005; Freed, 1990; Kunkler-Peck and Turvey 2000; Schiff and Oldak, 1990; VanDerveer, 1979; Warren and Verbrugge, 1984; Wildes and Richards, 1988.

[2] Gaver, 1993a.

am going to consider only material objects: material objects produce sounds when they are struck, tapped, scraped, broken, or otherwise caused to vibrate.

We generally picture vibrations as single sine waves, but not even something as simple as a plucked string vibrates in a simple way. The vibration of a plucked string is complex and comprises a number of simple vibrations at different frequencies which are integer multiples of the lowest, or fundamental, frequency of the vibration.[3] Objects vibrate along a greater number of dimensions than strings and consequently their vibrations have a greater number of frequency components. Any complex vibration is equivalent to a number of simple sine wave frequency components superimposed on each other with appropriate phase relationships. That means we can represent any complex vibration as a pattern or structure of individual phase-related frequency components.

What's important for our understanding of auditory perception is that the particular pattern of frequency components produced by a material object when it vibrates is determined in a law-like way by the physical nature of the object and the nature of the event that caused it to vibrate.

For example, the shape and size of the object determine the lowest frequency of its vibration, and what harmonics are present. The overall amplitude of the vibration is determined by the force that initially deforms the object. Because objects are not linearly elastic, the amplitude of individual frequency components varies with the initial deformation. The spectral composition of the vibration therefore changes according to how hard the object was struck (which is why we can distinguish in experience the intensity or loudness of a sound from the force of the impact that produced the sound; the first is a property of the sound, the second of the source of the sound). Vibrating objects lose energy over time and their vibration decays. The rate of decay of different frequency components is determined by the material of which the object is composed.

Because the pattern of frequency components that comprise the vibration of an object and the way that pattern changes over time is determined by the nature of the object and the events that caused it to vibrate, that pattern and the way it changes

[3] The vibration of a plucked string is made up of the odd harmonics of the fundamental; unlike the vibration of a string excited in some other way which includes both odd and even harmonics. See Fletcher and Rossing 1998, ch. 2.

embody a great deal of information about the object and the interaction that produced the vibration.

The vibrations of objects are transmitted through the air. In an enclosed space, the vibrations will tend to reflect off hard surfaces and surrounding objects, and vibrations from different objects will interact with each other. These reflections and interactions will change the spectral composition of a vibration in determinate ways. At any place, the local disturbance of the air at that place will carry information about any number of events and, in virtue having been structured by it, about the environment in which those events occur. This local disturbance of the air is what is detected by our ears.

From detection to perception

Auditory perception tells us about the sources of sounds. In order to do so it must extract the information about those sources embodied in the pattern of frequency components of the soundwave that is detected by the ears. The frequency components detected by the ears are the result of the interaction of many different object vibrations. How does the auditory system extract information about individual objects?[4] We can divide the process into three stages.

The first stage is that of sensory transduction or detection: the ears detect properties of the soundwave – the local disturbance of the air. We can think of the

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[4] Albert Bregman illustrates the problem as follows. Suppose that you are standing by a lake on which there are boats: "Your friend digs two narrow channels up from the side of the lake. Each is a few feet long and a few inches wide and they are spaced a few feet apart. Halfway up each one, your friend stretches a handkerchief and fastens it to the side of the channel. As waves reach the side of the lake they travel up the channels and cause the two handkerchiefs to go into motion. You are allowed to look only at the handkerchiefs and from their motions to answer a series of questions: How many boats are there on the lake and where are they? Which is the most powerful one? Which is the closer? Is the wind blowing? Has any large object been dropped suddenly into the lake? Solving this problem seems impossible, but it is a strict analogy to the problem faced by our auditory systems. The lake represents the lake of air that surrounds us. The two channels are our two ear canals, and the handkerchiefs are our ear drums. The only information that the auditory system has available to it, or ever will have, is the vibrations of these two ear drums. Yet it seems able to answer questions very like the ones that were asked by the side of the lake: How many people are talking? Which one is louder, or closer? Is there a machine humming in the background" (Bregman 1990, pp. 5-6).

result of the detection of the soundwave as a temporal spectrogram of the soundwave which encodes the frequency and temporal properties of the soundwave's vibration. In effect, the ears detect each of the frequency components (within a detectable range) present in the soundwave's vibration.

Information about objects and events is embodied in the relationships amongst the frequency components produced by an object's vibration; but the frequency components detected by the ears may have been produced by many different sources; so in order both to determine how many sound producing events are occurring at any time and to extract information about the objects involved in them – the auditory system must organise frequency components into groups corresponding to the objects and events that produced them. The second stage of processing therefore involves grouping together frequency components that have been produced by the same source. Frequency components need to be grouped so that all the frequency components produced by a single source are treated together, and those from different sources treated as distinct by subsequent processes.

There are two kinds of grouping. Frequency components produced at a time must be grouped together as having been produced *simultaneously* by a source; simultaneous groups must be *sequentially* grouped over time as having been produced by a single temporally extended event and series of such sequences grouped as having been produced by a series of events involving the same object.

For example, when two objects make a sound simultaneously we normally hear two distinct sounds – we hear the sound made by each of them; when we hear water filling a glass we hear a single continuous sound – we experience earlier and later parts of the sound as parts of the same sound; when we hear an object dropped onto a hard surface and bounce we hear the sound of each individual bounce and we hear the series of bounces as the bounces of a single object. We hear these sounds as a consequence of the way that frequency components are grouped. This grouping is necessary in order for subsequent auditory processes to extract the information about sources embodied in the soundwave.

How does the auditory system group frequency components, how does it determine which frequency components to group together and which to group separately? There are relationships that exist between components produced by the same source that are unlikely to exist between components produced by different sources. For example, an object's vibration often has frequency components that are harmonics of a fundamental frequency and so the frequency components of a soundwave that are produced by the same source will often be harmonically related. Such harmonic relationships are unlikely to exist between frequency components produced by distinct sources since it is unlikely that two simultaneously occurring natural events produce overlapping sets of harmonics. This means that if the auditory system detects a number of frequency components that are harmonically related then they are likely to have been produced by the same source. Similarly, the soundwave produced by a single event will have frequency components that share temporal properties – all the components will begin at the same time – are likely to be in phase with one another, and are likely to change over time in both amplitude and frequency in similar ways. Components produced by distinct sources are very unlikely to be related to each other in these ways. This means that if the auditory system detects a number of frequency components that share these temporal properties then they are likely to have been produced by the same source. When the auditory system detects these relationships between components it groups them together and treats them as having been produced by the same source. Components that are not related in this way are grouped separately. Similar relationships exist between frequency components produced by the same source at different times.

These examples are of properties that determine bottom-up or stimulus driven grouping. It is likely that the auditory system also uses information in a top-down way to determine grouping, particularly of sequences. Some sequences are grouped because they fit into a pattern that the auditory system recognises as likely to have been produced by a certain kind of source. Hearing an object as bouncing, for example, may be the result of top-down grouping.[5]

It is important to note that we cannot explain why the auditory system groups the frequency components that it detects in the way it does other than in terms of a process that functions to extract information about the objects that produced those frequency components. This is true of both simultaneous and sequential grouping. The auditory system groups together all and only frequency components that are likely to have been produced by the same source *because* they are likely to have been produced by the same source.

[5] Bregman calls this 'schema-based organisation': it involves 'the activation of stored knowledge of familiar patterns or schemas in the acoustic environment' (Bregman, 1990, p. 397).

The third stage of processing is not well understood. The process of grouping results in sets of frequency components that are treated by subsequent processes as having been produced by a single source. These sets of components carry information about those sources, and the fact that we can perceive various properties of the sources of sounds means that the auditory system must extract that information. Exactly what information is extracted and how it is extracted is, for the most part, unclear. We can perceive how many sources there are and often where they are; I've described examples of various features of sources that we can perceive, and examples of our ability to recognise sources as events of certain kinds or involving certain kinds of object. These recognition processes might match representations of the features of sources with representations of kinds of events and objects (similarly to the way visual object recognition functions), or they might simply track some characteristic pattern of frequency components produced by certain kinds of events and objects. However exactly the information extraction and object recognition processes work, they must – obviously – be sufficient to explain our capacity to perceive and recognise the sources of sounds.

Auditory experience

It is in virtue of the operation of these psychological processes we have experiences sounds and their sources. What sounds we experience and how we experience them to be is determined by the way the auditory system groups the frequency components it detects: the sounds we hear correspond to frequency component groupings. If the auditory system groups the components it detects into a single group then we experience a single sound; if it groups them into two groups, then we experience two sounds. Given that the auditory system groups frequency components that are likely to have been produced by the same source, the sounds we experience normally correspond to their sources – to the things that produced them.

Given that what sounds we hear is determined by the way the auditory system groups frequency components, and that we can only explain why the auditory system groups frequency components in terms of a process that functions to tell us about the sources of sounds, it follows that we can only explain why we experience the sounds we do in terms of a process that functions to tell us about the sources of sounds.[6]

What are sounds?

The auditory system functions to tell us about the sources of sounds. We experience sounds as a consequence of the way the auditory system carries out this function: the sounds we experience are the result of the way the auditory system groups the frequency components that it detects in order to extract information about the sources that produced them.

Given this, it is plausible that our experience of sounds represents patterns or structures of frequency components instantiated by the soundwaves that are detected by the ears. It follows that an experience of a sound is veridical just in case it is produced by the pattern or structure of frequency components that would normally produce that experience. It is not veridical if it is not produced by any such pattern or if it is produced by a pattern that would not normally produce that experience.[7]

Our normal ways of individuating sounds allows that two people, in different – even very distant – places, can hear the same particular sound – you and I both hear the same sound when we hear the sound of a gunshot. To deny this would be to allow that a single event – a gunshot, say – produces more than one sound: a sound heard by me, and a sound heard by you at a distance. Since people at different places who hear the same sound are not – or need not be – affected by the same instantiation of frequency components we cannot identify particular sounds with *instances* of a pattern or structural type. Similarly, our normal ways of individuating sounds allows that two people hear the same sound even if they hear it as having different qualities. The sound of a gunshot heard close by may be different – louder, sharper – to that same sound heard at a distance; it is, nonetheless, the same sound. But again, since the instantiation of frequency components must be different in the two cases, and may even be an instance of a different pattern, the sound we both hear cannot be identical to an instance of a pattern type.

[6] This reverses the order of explanation assumed by most, if not all, other accounts of sounds. There is not space here to defend my account in detail; for a more detailed discussion see my 'Auditory Perception'.

[7] For further discussion, see my 'Auditory Perception'.

If sounds are not identical to instances of pattern types, then could they be the pattern types themselves? Our normal way of individuating them treats sounds as particular things such that we can allow that two sounds may be qualitatively the same – the same type of sound – and yet be distinct individual sounds. Two sounds that are indistinguishable, for example, are usually counted as distinct if they are produced by different sources. Thinking of sounds as pattern types doesn't allow us to make this distinction. Furthermore, if sounds are things that come into being when they are produced then for any sound there is a time before which it did not exist, a time at which it came into existence and, presumably, a time at which it will cease to exist; although instances of pattern types have these temporal properties, pattern types themselves do not.

Any account of sounds should, as far as possible, accommodate our normal ways of individuating sounds. The ontological category that comes closest to doing so is that of particularized types or abstract individuals: to view sounds as abstract individuals would be to view them as belonging to the same ontological category as symphonies and other multiply instantiated art works or words (on Kaplan's account of the ontology of words).[8] To claim that sounds are abstract individuals is not, of course, to deny that sounds are instantiated by soundwaves any more than to claim that words are abstract individuals is to deny that words are instantiated by, for example, patterns of ink on paper. It simply allows the possibility that a sound, like a word, may be instantiated at more than one place and time.

Where are sounds?

Having given some account of what sounds are I am now in a position to address the question of where they are located. I have suggested that sounds are patterns or structures of frequency components instantiated by a soundwave; if that's right, then we can only make sense of talking of the location of a sound in terms of the location of its instantiation. Soundwaves spread out from their sources and their identity and location at any time can be indeterminate; there may, therefore, be no very determinate answer to the question of where a sound is instantiated. Although it may

[8] This idea that sounds are abstract individuals was suggested to me by M.G.F. Martin. For Kaplan's account of the ontology of words, see Kaplan (1990).

not be possible to say exactly where a sound is instantiated, the sounds we hear are instantiated by soundwaves that affect us so, wherever else they may also be instantiated, when we hear them sounds are instantiated where we are.

The sounds that we hear are instantiated where we are but they are usually not only instantiated where we are; they are usually instantiated throughout a region of space that includes where we are. Of course that doesn't mean that we only ever hear part of a sound that affects us: sounds are patterns or structures that are instantiated by soundwaves and the entire pattern or structure is wholly instantiated wherever it is instantiated, including where we are. A sound can be instantiated in different regions of space at different times; therefore, just as the pattern of ripples on the surface of a pool of water can be said to move, sounds can be said to move.[9]

Is this account of sounds inconsistent with our experience of sounds? Several writers have suggested that it is.[10] They claim that we hear the location of the sources of sounds and that we experience sounds as located *at* their sources – they claim that sounds *seem* to be at their sources. If that's right then any account of what sounds are must – on pain of being committed to a view according to which auditory experience is generally non-veridical – identify sounds with something located at their sources – events involving their sources or the vibrations of the sources. Whilst a perceptual system may always be susceptible to error, an account that has the consequence that the auditory system is always erroneous is implausible. Since the view that I have outlined entails that sounds are not, or not only, located at their sources it is, according to this objection, committed to viewing auditory experience as generally non-veridical and, as such, it is an implausible view.

A satisfactory response to this phenomenological objection must address two worries. First, can the account that I have given explain how we are able to perceive the location of the sources of sounds? Second, is my account inconsistent with the phenomenology of our auditory experience and committed to viewing auditory experience as generally non-veridical? Before directly addressing those two worries I want to say something about the role of space in the auditory processes that I have described. Understanding that role will help to answer these questions.

[9] Although sounds can be said to move, we don't experience them as moving (and, indeed, what would be the *point* in hearing sounds move?).

[10] For example, Pasnau (1999); Casati and Dokic (1994, this volume); and O'Callaghan (2005).

2. Space in auditory perception

What role does space play in auditory grouping? Grouping is the process, remember, by which the frequency components detected by the ears are grouped so as to correspond to their sources. The fact that a group of components all come from the same location is good evidence that they have been produced by the same source and the fact that two components come from different locations is good evidence that they were produced by distinct sources, so we might expect spatial location to play a role in both simultaneous and sequential grouping.

Spatial properties have an influence on grouping, but even when frequency components can be spatially distinguished they are not necessarily grouped according to their spatial properties. Frequency components from the same location are not grouped if other non-spatial cues – such as shared onset times and harmonic relationships – conflict with spatial cues, and frequency components from different locations may be grouped if non-spatial cues indicate that they have the same source. Our experience of music played over stereo loudspeakers is a good example of this. Frequency components produced by spatially distinct sources – the loudspeakers – may be grouped to produce an experience of a single sound, perhaps with an apparent source that is located at a place in between or behind the speakers. This happens because the spatial cues to grouping are weaker than the non-spatial cues: the pattern of frequency components produced by the two speakers is more likely[11] to have been produced by a single sound source whose spatial cues have been disrupted than to have been produced by two sources. Diana Deutsch's 'scale illusion' is an example in which a sequence of sounds is heard as grouped into a sequence despite the fact that individual sounds come from different locations.[12]

What both these examples demonstrate is that spatial properties are only a weak cue to frequency component grouping, a cue which can be overridden by non-spatial cues. This makes ecological sense given that the auditory system functions to group frequency components that correspond to their sources. The transmission of

[11] By 'more likely' I don't mean true in the closest worlds (it wouldn't be more likely in that sense for someone who heard only artificially produced sounds) but to have been produced that way in the recent evolutionary history of the auditory system.

[12] For a description and discussion of the illusion see Deutsch (1974, 2004) and for discussion see Bregman 1990, p.76.

sound waves – with frequency components being detected only after they have been reflected off and refracted around surfaces – disrupts spatial cues and makes them unreliable. Their unreliability means that other non-spatial cues are a better guide to correct grouping and correct grouping according to spatial cues will only reliably correspond to sound sources if those spatial cues are supported by other non-spatial cues.

Although spatial properties can have an influence on auditory grouping they are not necessary for grouping. Frequency components can be appropriately grouped even when they cannot be spatially distinguished. This is evident from the fact that we can hear sounds produced by different sources as distinct when their frequency components all come from the same location: components are grouped as distinct despite being spatially indistinguishable. This happens, for example, when sounds are played over a single loudspeaker, such as a radio, or when different sound sources are all heard from behind a barrier or wall. Frequency components from sources which are behind one another relative to the listener will tend to have the same spatial cues and so be spatially indistinguishable, yet may be heard as distinct.

The fact that spatial cues are not necessary for grouping should lead us to question in what sense grouping is ever genuinely spatial at all. Frequency components are not themselves intrinsically spatial, nor is the way in which they are detected.[13]

Spatial information about the location of the source of a frequency component must be recovered from time, intensity, and phase differences between each ear's detection of that frequency component. These relations between the frequency components detected by each ear carry information about spatial location, but they don't have any intrinsic spatial significance: there is no intrinsic connection between the phase and temporal relationships of frequency components and spatial properties. Frequency components only gain spatial significance by being interpreted or encoded in a spatial way.

But such a spatial interpretation or encoding isn't necessary for the properties that encode spatial location to play a role in frequency component grouping.

[13] Neurons of the basilar membrane, which detect properties of the soundwave, are organised in a tonotopic way, unlike the neurons of the retina which are spatially organised (with the consequence that spatial information is embodied in the spatial pattern of the stimulation of the retina as well as in the binocular differences in the stimulation of the two retinas).

Common inter-aural time and phase differences can be used as an indication of correct grouping independently of frequency components or groups of frequency components having been encoded within a spatial framework. That means that components don't need to be assigned spatial properties or coordinates and then grouped on the basis of shared or different spatial properties or coordinates, they can simply be grouped on the basis of temporal and phase relationships. If components are grouped on the basis of temporal and phase relationships then they will be grouped according to whether they come from the same or a different location, but the process of grouping will not be a spatial process – it will not operate on or use spatial properties to determine grouping. We can therefore explain the role that the spatial location of the source of a sound has in grouping frequency components – we can explain how frequency component groupings track sameness and difference in spatial location – without supposing that the processes or grouping are themselves spatial, that they operate on or use spatial properties.

The fact that spatial cues are not necessary for grouping suggests that frequency component groupings are not spatially individuated: distinct groups of frequency components are not distinct in virtue of having different spatial properties. Given that the auditory system's grouping of frequency components determines what sounds we experience, the fact that groupings are not spatially individuated suggests that sounds aren't either. It would follow that it is possible to experience two sounds as distinct without experiencing them to be spatially distinct. If my argument is right that grouping is not spatial even when it exploits properties that track spatial differences, then frequency component groupings do not have spatial properties. Again, given that the auditory system's grouping of frequency components determines what sounds we experience, the fact that groupings don't have spatial properties suggests that sounds don't either. It suggests, in other words, that sounds don't have any *intrinsic* spatial significance and don't have any spatial structure.[14]

[14] This contrasts with vision. Visual features have spatial properties in virtue of the way they are detected: the retina detects a spatially distributed pattern of light and preserves that spatial mapping through subsequent processing. As a consequence, visual features have an intrinsic spatial significance: they stand in spatial relations to each other without needing to be interpreted spatially (though they may be mapped into other frames of reference for other purposes). There are visual processes – analogous to auditory grouping processes – that bind together different visually detected features as features of a single object. The best explanation of how features belonging to a single object are bound

Reflecting on our experience of sounds supports these suggestions about sounds. We often hear two sounds as distinct without them having or seeming to have different spatial properties; we do so when we listen to music on a radio that has a single speaker, or hear sounds coming through the window of the room we are in. In such cases we hear simultaneous sounds as distinct, and can focus our attention on one to the exclusion of the other, without being able to distinguish them spatially; if our attention is focussed on a place it is always the same place, therefore when we focus our attention on one sound rather than another we do not focus our attention on one place rather than another. We don't hear sounds as having spatial parts or as having a spatial structure: although we can make sense of a sound having *temporal* parts – in virtue of the fact that we hear sounds as temporally extended – we cannot make sense of *spatial* parts of sounds: hearing simultaneous sounds as having distinct spatial properties is sufficient to hear them as distinct sounds, so we cannot simultaneously hear distinct parts of a *single* sound as standing in spatial relations to one another. If we don't hear sounds as having spatial parts then it cannot be that what makes simultaneous parts of a sound seem to be parts of single sound is that they are spatially related, a conclusion that is supported by the fact that it is possible to hear sounds without hearing them as having *any* spatial properties. The same is surely true of the temporal parts of sounds and sequences of sounds. When we hear a melody we hear a sequence of sounds *as* a sequence. As the example of listening to music on the radio shows, hearing the elements of this sequence as such is not a matter of hearing them as sharing spatial properties.

The claim that sounds are not individuated spatially has empirical support. A soft sound tends to disappear – is masked – if a louder sound of a similar frequency is heard simultaneously; however, if the louder sound is spatially separated from the softer sound the masking effect is reduced and it is possible to hear the softer sound. Thiran and Clarke describe a subject, NM, with a spatial hearing deficit.[15] NM can hear sounds and recognise their sources, but cannot localise them or perceive them as

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together is that binding processes exploit spatial properties, binding together as features of a single object those features which share spatial properties. Spatial properties are necessary for visual binding, and hence necessary for object identity. The spatial properties that individuate visual objects in early vision are properties of the visual field, and are independent of any mapping of visual objects into an egocentric frame of reference.

[15] Thiran and Clark 2003; see also Darwin and Hukin 1999.

moving; sounds presented at different azimuthal positions seem to her all to be at the same position. Despite this spatial deficit, NM experiences the release from masking effect: she cannot hear a soft sound when the masking sound was in the same position as the soft sound, but can hear it when they are spatially separated. When asked to report the location of the masking sound she said that she always heard it in the same place, superimposed on the softer sound. For this subject spatial properties play a role in grouping sounds and so in determining what sounds she experiences, but in a way that doesn't enter in to the content of her experience: she hears sounds as distinct without experiencing them as spatially distinct and she doesn't experience sounds as having spatial properties.[16]

Although the processes that determine what sounds we hear are not intrinsically spatial, our auditory experience is, or can be, spatial: we can hear where the sources of sounds are. For us to be able to hear the locations of the sources of sounds the auditory system must extract spatial information about the locations of the sources from the groups of frequency components that it detects and from the differences between the groups detected by each ear. If what I have already argued is correct, the auditory system doesn't interpret individual frequency components as having a spatial significance; it first groups frequency components from a single source, and then extracts from the group spatial information about the source. The process that extracts spatial information occurs as part of the third stage of auditory processing – the stage that functions to extract information about sound sources. This process is distinct from the second stage of grouping processes that I have described. Spatial location is one of a range of properties of the source of the sound, information about which the auditory system extracts from frequency components that have been grouped to correspond to their source.[17]

What kind of spatial information does the auditory system extract? It can only extract what spatial information is available. Spatial information about sound sources

[16] Although she describes or indicates the sounds as originating at the same *place*, it's plausible that they don't seem to her to be located or come from anywhere and that she makes her indication only because of the requirements of experiment (in conversation, Clarke has agreed that this is a plausible interpretation of NM).

[17] This suggests an interpretation of the "'what' and 'where'" distinction in auditory perception which is at odds with the dominant view in psychology; for an elaboration and defence see my 'What and Where in Auditory Perception'.

is (for the most part)[18] embodied in the differences in phase, time, and intensity of groups of frequency components detected by each ear. This information concerns the location of the source of the sound relative to the perceiver's head. The initial interpretation of the location of a sound source will therefore be in a head or body centred frame of reference – one that represents the location of the source of a sound relative to the perceiver's head or body. As a consequence of the fact that we perceive the locations of sources relative to where we are is that we can, immediately and without calculation, turn our heads or point in the direction of the source of a sound we hear. We also perceive the locations of sound sources relative to one another – we can hear, for example, that one source is to the left of another. Our perceptual system must therefore map the head or body-centred locations of sound sources into other non-egocentric frames of reference (perhaps frames of reference shared with other senses).[19] However, given the way that spatial information is embodied in soundwaves it is possible to map the location of a sound source in a non-egocentric frame of reference only if it has first been located egocentrically. It would seem to be necessary, therefore, that if we experience the source of a sound as having a location we experience it as having a location relative to where we are.

3. The Spatial Phenomenology of Auditory Experience

The objection to the view of sounds that I outlined at the end of section 1 is that sounds seem to be located where their sources are. This is a phenomenological claim, a claim which is supported by appeal to how things experientially seem. To answer this objection I will first describe the way in which sound *sources* seem to be located and then ask in what sense, if any, sounds seem to be located *at* their sources.

In his well known discussion of sight and touch Mike Martin draws a contrast between the different ways we experience space and objects as located in space. He points out that in vision we are aware of a region of space within which we can experience objects – that we experience space itself *and* objects in space – whereas in touch we experience the location of parts of objects that we are aware of as extended

[18] Reflections play a role too but not in a way that undermines this line of argument (see Bluert 1997, sec 2).

[19] See Spence and Driver, 2004, especially chapters 10 and 11.

in a space that extends beyond the limits of our experience, but which is itself experienced. He illustrates the contrast with an example:

> Consider the case of looking at a ring-shaped object, a Polo mint, for instance, head on. One is aware of the various white parts of the mint arranged in a circle, and aware of how they are related to each other. One is also aware of the hole in the middle of the mint, and that that hole is there in the middle. If one was not aware of the hole one would not see the mint as ring shaped rather than a circle. Nothing need be perceived to be within the hole. One is aware of the hole as a place where something potentially could be seen, not as where something is actually seen to be… So we can think of normal visual experience as experience not only of objects which are located in some space, but as of a space within which they are located. The space is part of the experience in as much as one is aware of the region as a potential location for objects of vision (Martin, 1992, p.199).

This description of an experience as *of* space doesn't seem an appropriate description of our tactile experience:

> when one grasps the rim [of a glass] one comes into contact with it at only five points, where one's fingertips touch it. Nevertheless one comes to be aware that the glass as a whole is circular. In being tactually aware in this way, is one aware of the parts of the rim in between the points of contact in the same way as one is aware of those points, and is one aware of the region of space lying inside the rim? The answer would appear to be not: one comes to be aware of the glass by being aware of the parts one touches. In this it contrasts with the Polo mint, since one is aware both of the ring-surface and the hole in the same way (*ibid*, p.200).

The description of visual experience as an experience *of* space doesn't seem appropriate as a description of our auditory experience either. Suppose that you hear two sound sources as located one in front and to the left and one in front and to the right of you: you are aware of the locations of the sources and aware that they are a certain distance apart separated by a region of space. Your awareness of these places is similar to the tactile awareness you might have of the rim of a glass. Just as in the tactile case, where we are aware of the rim at the points we touch it and there is a contrast between our awareness of the locations of the points of contact and our awareness of the space between those points, in the auditory case you are aware of places in virtue of hearing something to be located there and there is a contrast between the way in which you are aware of the places where you hear something to be and your awareness of the region of space that separates those places. In both touch and hearing the space that separates the experienced locations is not itself an object of the experience. In neither case are we aware of the region of space between the places we experience something to be in the way that we are visually aware of the empty space that is the hole in the Polo mint. In this respect, then, the phenomenology of our auditory experience of space is more similar to the phenomenology of our tactile than to our visual experience of space.

But this poses a puzzle. In order to mark the phenomenological differences between our visual, tactile, and auditory experiences of things in space we seem compelled to say that although in vision we are aware of space, this is not true of touch or hearing: in touch and hearing we are aware of things in space, but we are not aware of space itself. However, there's a sense in which our auditory and tactile experiences *do* provide us with an awareness of space. Although we only touch the rim of a glass at five points we are aware of the rim as circular and so as occupying the space in between the points we touch; although we hear the location of two objects relative to one another we are aware of them as separated in space and so aware of the space in between where we hear them to be. One the one hand, in order to mark the phenomenological differences, we need to deny that we are auditory and tactually aware of space; on the other hand, we can only explain how we are auditorily and tactilely aware of things in space by supposing that we have both an auditory and a tactile awareness of space. So we both do and do not have a tactile and auditory awareness of space.

The problem is to explain the phenomenological contrast, in tactile and auditory experience, between our awareness of the places we experience something to be and our awareness of the places where we don't experience anything to be (those places, for example, in between the places we experience things to be), and so to give some account of how we are aware of places we don't experience anything to be.

Prima facie this doesn't seem possible within the framework of a representational theory of perception.[20] A representational theory of perception explains what it is to experience something in terms of the representational content of an experience. We have an experience of something in virtue of our experience representing it as being some way. To say that we are experientially aware of something is then just to say that we are aware of it in virtue of having an experience of it. But that means we cannot draw a distinction between experiencing something and being experientially aware of it. We can either say that we are aware of space in virtue of our experience representing that space, or that we have an experience of space in virtue of our experience representing it. Both amount to the same thing. How then do we draw the contrast we need to explain the differences between visual, tactile, and auditory experience of space?

The suggestion that I want to explore is that we can explain the contrast in terms of the determinacy with which spatial properties are represented by different experiences. What does it mean to say that something is represented more or less determinately? I have in mind the intuitive idea that an experience can tell us more or less about some region of our environment by representing that region and the objects and properties within it in greater or less detail, in a more or less determinate way.

We are familiar with the idea that pictures can represent more or less determinately. A colour photograph of an apple tells us more about the apple than a black and white photograph does; the black and white photograph doesn't tell us what colour the apple is, whether it is red for example. A black and white photograph neither represents that the apple is red nor that the apple is not red. We shouldn't think of a black and white photograph as *mis*representing the colour of the apple – as representing it to have a colour it doesn't have – it is simply silent on the question of the apple's colour and so doesn't represent the apple as having a determinate colour. Similarly, an outline drawing of a bird is in many respects indeterminate. It doesn't represent the colour of the bird, nor whether the bird has feathers, nor whether the surface of its back is different to that of its legs. Again, it is not that the drawing is misleading; it is just not very informative. It doesn't tell us much about the bird, whether it has or lacks certain properties; it is, in certain respects, indeterminate.

[20] A point made by M.G.F. Martin (1992).

This idea of a representation representing in more or less determinate ways can be applied to perceptual experience. A perceptual experience represents the perceiver's environment as being some way in virtue of having representational content. We can specify the representational content of a perceptual experience by specifying those ways which the perceiver's environment can be that are consistent with the representational content of the experience being correct. Thought of this way, the representational content of an experience specifies a set of ways the perceiver's environment can be and the experience is veridical only if the perceiver's environment is one of those ways. The same approach can be used to specify the way in which an experience represents an object: we specify which ways the object can be that are consistent with the representational content of the experience being correct. A perceptual experience whose content is relatively determinate will specify a narrower set of ways that things could be; by telling us more about how things are it narrows down the possible ways things could be. An experience whose content is relatively indeterminate will specify a wider set of ways that things could be; by telling us less about how things are, it allows a greater number of possible ways things could be. We can use this notion of the indeterminacy of experience to explain the differences between visual and tactile experiences of space.

For example, a visual experience that represents the rim of a glass as circular is more determinate than a tactile experience that represents the rim of a glass as circular; the visual experience narrows down the ways a certain region of space could be far more than the tactile experience. It does so because it tells us more about the rim, the glass, and the space around the glass: it represents the rim of the glass as circular and for a region of space – the region that is visible from the subject's point of view – it represents, for every location within that region, either something as at that location or that location as empty. The experience is veridical only if the visible region of space is occupied at those locations where something is represented to be, and empty at those locations where nothing is represented to be. It is because it represents every location within a region of space as determinately occupied or empty that visual experience is an experience of space as well as objects in space. A tactile experience of the rim of the glass represents the rim of the glass as circular, and so represents the rim as occupying a region of space that extends between the points of contact with the glass, but is silent about the larger space within which the rim of the glass is experienced to be: it doesn't represent any location within that larger space as either occupied or as empty. That means that there are many ways that larger space could be that are consistent with the experience being veridical. There could, for example, be a circular piece of opaque card stuck just inside the rim of the glass. The tactile experience doesn't rule out such a possibility, whereas the visual experience does. By representing the rim of the glass as occupying a larger region of space, the tactile experience represents spatial locations that are not locations of parts of the rim; however, unlike visual experience, it doesn't tell us anything about those locations – it doesn't represent them as occupied or as not occupied – and so doesn't provide us with an experience *of* the space. As a consequence of these differences, there are far fewer ways that the region of space could be that are consistent with the visual experience being veridical than are consistent with the tactile experience being veridical. Similarly, the visual experience of the rim of the glass represents each part of the rim in an equally determinate way. In contrast, the tactile experience of the rim of the glass represents the parts of the rim at the points of contact more determinately than the parts in between the points of contact. We are aware of the texture of the rim at the points of contact, for example, but not at the points in between. Therefore the experience tells us less about the parts of the rim in between the points of contact than it does about those points; this difference explains the contrast between our awareness of the rim at the points of contact and our awareness of the points in between. Although both visual and tactile experiences tell us that the rim is circular, because it tells us more about the rim of the glass and the surrounding space there are fewer ways the rim could be that are consistent with the visual experience than with the tactile experience being correct.[21]

This explains the different ways in which we are aware of space in touch. A tactile experience tells us about the places we experience something to be – that they are occupied – and it tells us that there are places in between the places we experience

[21] Amodal completion provides the closest visual analogue of our tactile experience of shape. The fragmentary outline of an occluded circle may still be seen as circular – the fragments are experienced as parts of a circle – but there is a contrast between our visual awareness of the visible fragments and our awareness of the parts of the circle that are occluded. When we see the letter B obscured behind a squiggle (see diagram) we experience only parts of the letter, but are aware of the surface as forming the letter B. Our experience represents the letter as shaped like a B and so represents the surface as extending underneath the squiggle. But we don't *experience* the surface underneath the squiggle we just experience those parts of the letter that are not obscured.

something to be; but it tells us nothing about those in-between places. It doesn't tell us, for example, whether or not they are occupied. There is, therefore, a contrast between our awareness of the places we experience something to be and our awareness of the places in between.

We can explain the phenomenological differences between vision and touch, in particular the differences in our experience of space, by appealing to the determinacy of the content of visual and tactile experiences. We can explain the phenomenology of our auditory experience of space in a similar way.

Our auditory experiences represent space in a way that is often far less determinate than either visual or tactile experience. This is most obviously true of an experience of a sound source that doesn't seem to be located anywhere. Such an experience is indeterminate with respect to the location of the source: it doesn't tell us anything about where the source is located and its veridicality is independent of the actual location of the source. When we do experience the source of a sound as located, our experience may tell us more or less about where the source is. We may experience a source as being outside of the room, as being somewhere over on the right, or as being over on the right and just in front of us. In each case the experience veridically represents the location of the source just in case it is somewhere outside the room, or somewhere to our right, or somewhere to our right and in front. The experiences differ in the determinacy with which they represent the location of the source; greater determinacy corresponds to smaller regions of space within which the source must be located if the experience is to be veridical. Our auditory spatial acuity is relatively poor so even in the best circumstances the most determinate auditory experience is quite indeterminate about spatial location.

Auditory experience doesn't tell us anything about regions of space other than those where we experience sound sources to be. If we experience the source of a sound to be over on our right and another source to be over on the left then we are aware of their being separated by a region of space, and our experience represents the spatial relation between them; but it doesn't tell us anything about that space, in particular it doesn't tell us whether there is anything at the places in between the places we hear the sources to be. It doesn't represent those locations as either occupied or as empty.

Whilst it is true that we experience the location of the sources of sounds and that sound sources seem – phenomenologically – to be located, simply saying that sound sources seem to be located obscures the differences between the way auditory and visual experience represents the spatial location of objects. Sound sources seem to be located in a different way to the way objects that we see seem to be located. In particular, sound sources seem to be located only in virtue of seeming to be somewhere relative to where we are and to other sound sources: our auditory experience represents sound sources as located in space in virtue of representing them as standing in spatial relations to one another and to us.

Unlike visual experience, auditory experience doesn't represent empty places – it doesn't represent places as unoccupied. That means that auditory experience only represents spatial relations between the locations where we experience the sources of sounds to be, and between those places and us. Visual experience represents both the locations of objects and of places as unoccupied, and it represents spatial relations both between the locations of objects it and between those objects and places it represents as unoccupied. Auditory experience doesn't represent places as unoccupied and doesn't, therefore, represent the spatial relations between the locations of sound sources and of unoccupied places. Visual experience represents objects and parts of objects, and the spatial relations between objects and their parts. Auditory experience doesn't represent sound sources as having parts and so doesn't represent parts of objects as spatially related to one another. Unlike our visual experience, our auditory experience of space is exhausted by our awareness of spatial relations between sound sources and us, and between sound sources and other sound sources. Our visual awareness of space is not exhausted by our awareness of objects as spatially located relative to each other and to us. Visual experience represents the spatial properties of objects and it represents objects as having parts that are spatially related to one another; visual experience represents places, whether occupied or not, and so represents spatial relations between places and objects; we are aware of the spatial relations of objects to space itself – to places where we experience nothing to be.

There are, then, significant differences between our visual experience of the location of objects and our auditory experience of the location of objects, and so between the sense in which objects we see *seem* to be located and the sense in which the objects we hear *seem* to be located, and it doesn't follow form the fact that sound sources seem to be located that they seem to be located in the same way that visual objects seem to be located.

We experience the sources of sounds as located; do we experience sounds as located? Sounds do not seem to be located anywhere other than their sources; therefore, if sounds seem to be located they must seem to be located where their sources are. To answer the question, then, of whether sounds seem to be located we need to answer the question of whether we experience sounds as located where we experience their sources to be. When we hear the alarm clock ringing we can hear where the clock is – that it is on our left-hand side – do we also hear where the sound of the alarm clock is – does the sound of the alarm seem to be where the alarm clock seems to be?

One model for how sounds might seem to be located is a visual one. We can see a pattern or mark as located where an object is located by seeing the pattern as a pattern on the surface of the object. Suppose, for example, that we see a cube with a cross marked on one of its faces. We can see where the cube is – we experience the cube as having a location – and we experience the cross as located where we experience the cube as located. The cross seems to be where the cube is because it seems to be on the surface of the cube, and the cross seems to be on the surface of the cube – at least in part – because it has spatial parts that we experience as spatially related to parts of the surface of the cube. This explanation of the cross seeming to be where the cube is depends on both the pattern and the cube having spatial parts and our experiencing parts of the pattern as spatially related to parts of the cube.

In this example the pattern and the object can both be identified independently of one another and each has a spatial location: in seeming to see the pattern as on the surface of the cube we seem to see it as having the *same* location as that of the surface. Its having the same location as the cube is a contingent matter. We could see the pattern as being located elsewhere, and in seeming to see the pattern as on the surface of the cube our experience may mislead us. The pattern could be located elsewhere and merely appear, as the result perhaps of an arrangement of mirrors, to be located on the surface of the cube.

This model, of two independently identifiable objects which can differ in location but which are experienced as having the same location – as sharing spatial properties – is the only one according to which it could follow from the *spatial* phenomenology of experience that one object has the same location as another object. Each object seems to have a location and both seem to have the same location. It's not a model that applies to our auditory experience of sounds and their sources. We don't experience sounds as having a spatial location independently of their sources having a spatial location, nor do we experience sounds as having spatial parts, so we don't experience sounds as having the same spatial location as their sources, nor as having parts that stand in spatial relations to parts of their sources. If sounds seem to be located at their sources it is not *because* they seem to have the same location as their sources.

Can sounds seem to be where their sources are other than in virtue of seeming to share spatial properties with their sources? Perhaps, by analogy with colour, they can. The surfaces of objects appear coloured: when we see the surface of an object as coloured the colour seems to be where the surface is. The colour doesn't seem to be where the surface is in virtue of seeming to share spatial properties with the surface; it does so because it seems to be a property or quality *of* the surface. Because of the way they seem, any account of what colours are that claims that colours are not properties of surfaces must view the phenomenology of our experience of colours as misleading and so is committed to an error theory of colour experience.[22]

The phenomenological objection to my account of sounds may best be understood in a similar way: sounds seem to be properties or qualities of the objects that are their sources and so seem to be located where those objects are located – not in virtue of sharing spatial properties with those objects, but in virtue of seeming to be properties or qualities *of* them. It would follow that any view of sounds that claims that sounds are not properties of objects and not located where those objects are located must view the phenomenology of our experiences of sounds as misleading and so is – unacceptably – committed to an error theory of auditory experience. If that's right then it's not that my account of auditory experience gets the *spatial* content of that experience wrong; it fails to accommodate the fact that sounds seem to be qualities of objects.

Is an objection along these lines right – do the sounds we experience seem to be properties of their sources in the same way that colours seem to be properties of the surfaces of objects? To answer that question we need first to determine what it is about our experience of colours that makes it correct to describe them as seeming or appearing to be properties of the surfaces of objects. Although it is widely agreed that colours *do* seem that way, what it is about how they seem that makes that description

[22] Of the kind proposed by Boghossian and Velleman (1989).

appropriate is not often discussed. There are, nonetheless, features of the appearance of colours that make that description appropriate.

The way the colour of a surface appears is determined by both the colour of the surface and the way that the surface is illuminated. The way a surface appears – in particular the way the colour of a surface appears – changes according to how the surface is illuminated. For example, a surface of uniform colour that has a shadow cast on it has a different appearance to a surface without a shadow cast on it. Such differences in the way the colour of a surface appears do not normally appear to be differences in the colour of the surface; they appear to be what they are: differences in the way the surface is illuminated.[23] Normally, we can distinguish in our experience between differences in how the colour of a surface appears which are due to variations in the colour of the surface and differences in how the colour of a surface appears which are due to variations in how the surface is illuminated.

Our ability to make this distinction in our visual experience depends on the fact that the colour of a surface can appear to be constant through changes in illumination. To see a shadow on a surface as a shadow is to see it as a discontinuity in the illumination of a uniformly coloured surface rather than as discontinuity in the colour of a uniformly illuminated surface. (Conversely, to see a discontinuity as a discontinuity in the colour of the surface is to see a change in the way the surface appears as independent of its illumination.) We cannot explain the appearance of the colour of the surface other than in terms of the way two things appear to interact: the colour of the surface appears to interact with the light illuminating it.

It is because we can distinguish between those changes in the way the colour of the surface appears that are due to variations in the apparent colour of the surface from those that are due to apparent variations in the way the colour is illuminated that it is correct to describe colours as seeming to be surface properties of objects – as properties of surfaces that stay constant through changes in illumination and which partly determine how the surface appears. If we could not make this distinction then colours would not seem to be properties of the surfaces of objects. Sometimes (when,

[23] That they appear this way is not the result of our *judging* that a variation is a variation in illumination rather than a variation in the surface; it's a matter of how they experientially appear. That variations in illumination appear differently to variations in surface colour is a consequence of the operation of colour and lightness constancy mechanisms in visual processing. See Gilchrist (2006) for a state of the art discussion of the mechanisms of lightness constancy.

for example, a surface is viewed through a reduction screen that prevents the perception of its illumination) it is not possible to tell whether a change in the appearance of a colour is a variation in the surface or a variation in the illumination of the surface. In such cases the colour does not seem to be the colour of the surface, but has the appearance of what Katz called 'film' colour – colour that appears transparent and is looked through rather than at.[24]

Are there similar features of the appearance of sounds that would make the description of sounds as apparent properties of objects appropriate? The appearance of the sounds we hear is determined both by the character of the vibration of the object that produced the sound and by the way that vibration is altered during its transmission from its source to our ears. To justify the description of sounds as seeming to be properties of the objects that produce them there should be a similar pattern within our experience of sounds as there is within our experience of colours: the way sounds appear should be explained as the result of the apparent interaction of the sound-of-the-object and the transmission of the sound. That is, the way sounds appear should appear to be the result of the interaction of the-sound-of-the-object and the way the-sound-of-the-object interacts with its environment. Then sounds would appear to be properties of their sources similarly to the way that colours seem to be properties of surfaces.

The appearance of a sound does not *appear* to be the joint upshot of the apparent sound-of-an-object together with the apparent alteration of the sound during transmission. That is, we cannot distinguish *in experience* between aspects of how sounds appear which are due to the sound-of-the-object, and aspects of how sounds appear which are due to alterations of the sound during transmission. The appearance of a sound is simply determined by how the sound we hear appears to be. (Contrast this with colour: the appearance of a colour – for non-film colours – is not simply determined by how the colour appears to be, but by how the colour appears to be together with how the colour appears to be illuminated).

We can, of course, distinguish in auditory experience between how a sound appears to be and how the source of that sound appears to be. How a sound appears can change without the source of that sound appearing to change. A sound may

[24] Katz wrote that "a complete impression of illumination is had only where objects are perceived, and … whenever objects are perceived an impression of illumination is always produced" (Katz 1935, p.10).

appear to be quieter, for example, without the event that produced it appearing to change. When we close the window to shut out the sounds of the traffic the sounds we hear get quieter, but what is making the sounds doesn't appear to change; when you pull your hat down over your ears the sounds you hear become muffled, but the things producing those sounds appear unaltered. What appear not to change are the objects that produce the sounds, not the sounds that they produce; the sounds they produce *do* appear to change – they appear to be quieter or muffled. It's not that the sound-in-the-object appears to be unchanged through changes in how the sound appears; it's that the object appears to be unchanged through changes in how the sound appears to be. The sound-in-the-object doesn't appear to be any way at all.

There are no grounds, therefore, for our saying that the sound-in-the-object appears responsible for how the sound appears in the way that the surface colour of an object appears responsible for how the colour of the surface appears; and no grounds, therefore, for saying that sounds seem to be properties of objects rather than things produced by objects. In fact, the opposite is true. That sounds can appear to change,[25] and can be changed, without their objects appearing to change is what leads us to describe sounds as seeming to *come from* their sources, and makes such a description appropriate.

Sounds don't seem to be at their sources in virtue of sharing spatial properties, nor in virtue of seeming to be qualities of their sources. Therefore, the phenomenology of auditory experience is not inconsistent with an account of sounds, such as mine, according to which sounds are not located at their sources. In fact, the opposite is true: the account I have given is not only consistent with that phenomenology, it provides the best explanation of it.

[25] Note that although sounds appear to change independently of objects, the same is *not* true of colours. The appearance of the colour of a surface can change independently of the surface of the object appearing to change, but such a change is not a change in the apparent colour of the surface; it is a change in the apparent illumination of the surface. If the apparent illumination is held fixed then the appearance of the colour of the surface can only change if the colour of the surface – and so the object – appears to changes.

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